PACKET STORE-AND-FORWARD COMMUNICATIONS SATELLITES FOR RELIEF AND DEVELOPMENT

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ABSTRACT

The early history of proposed small satellites in low earth orbit using store-and-forward digital technology for humanitarian relief and development work is reviewed. A description of the current status of the PACSAT project being developed jointly by SST Ltd and VITA is is provided. The need to decrease the turnaround period of time-dependent technical information to and from isolated regions of the world is described, as well as limitations to project success when the right information is not available at the right time. Major PACSAT applications areas in relief and development are presented, and a functional description of several tiers of PACSAT groundstations is given. Sociological and regulatory concerns are overviewed. The paper concludes that packet radio systems, in both terrestrial and space applications, have the potential to provide "the missing link" of reliable and inexpensive communication from isolated regions integrated into the existing international telecommunications infrastructure.

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INTRODUCTION

Early History

Satellites in low earth orbit (LEO) using store-and-forward digital technologies have been proposed for international relief and development work since the early 1980's.

One of the major conclusions of a workshop sponsored by the International Development Research Centre (IDRC) in Ottawa On "Computer-based Conferencing Systems for Developing Countries" (October 1981) was that the IDRC support feasibility studies for both "the development of low-cost, narrow-band ground stations for research institutions" and "international nongeostationary satellites for computer-based conferencing in developing countries." Presenters at that meeting included S. Ramani (Bombay) and R. Miller (California) who proposed "a new type of communication satellite needed for computer-based messaging" in equatorial orbit for developing countries. Digital methods suggested included radioteletype, telegraphy, and broadcast videotex (Ref. 1).

Curiously, at exactly the same time (October 1981), the American Radio Relay League (ARRL), a noncommercial association of radio amateurs, sponsored the first "ARRL Amateur Radio Computer Networking Conference" along with two other amateur radio special interest groups, the Radio Amateur Satellite Corporation (AMSAT) and the Amateur Radio Research and Development Corporation (AMRAD). At this meeting, the first public mention of "PACSAT", a proposed LEO satellite using packet radio technologies for store-and-forward digital communication among radio amateurs was made. Fig. 1 illustrates the basic operation of the PACSAT system.

Apparently, neither meeting was known to the other. In March 1982, Dr. Yash Pal, an eminent Indian space scientist and Secretary-General of UNISPACE '82 (Vienna) proposed that an "orbital postman" using LEO satellites and digital methods be studied for some of the communication needs of the United Nations system (Ref. 2).

In early 1983, Volunteers in Technical Assistance (VITA), in consultation with IDRC, Dr. Pal and others, approached AMSAT to determine if interest existed in laying out the specifications for a PACSAT mission. VITA is a nonprofit organization offering information and assistance for the selection and implementation of technologies in developing countries. At that time VITA had accumulated nearly two years of real-time audio teleconferencing experience over ATS-1 on the Pacific PEACESAT network providing information on renewable energy technologies through lessons prepared by its volunteers. VITA believed that the PACSAT concept could represent an alternative to the transfer of technical information to isolated regions presently served by

PACSAT—Mission Profile

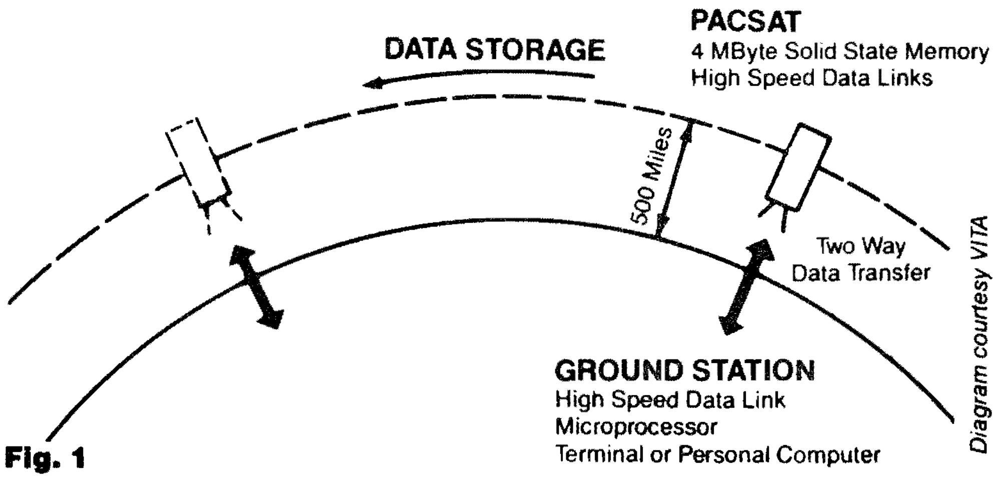

Fig. 1

PACSAT system architecture

unreliable methods (mail, telephone), if at all. Even PEACESAT had its drawbacks as an information dissemination tool, namely the difficulty in arranging for user groups to be present during the pre-arranged conference itself due to intervening factors as well as unavailability of hard copy records of questions and responses.

An agreement with AMSAT to jointly pursue development of a PACSAT mission was reached and in early 1983, with modest funding from VITA, AMSAT initiated a process which culminated in a Final Design Meeting near Boston attended by AMSAT and VITA personnel and volunteers. Participants at the meeting included staff from the UoSat Spacecraft Engineering Research Unit at the University of Surrey (Guildford, England). The Surrey team, which had earlier (1981) constructed and arranged for a NASA launch of UoSat-1 that had successfully demonstrated the "highly sophisticated functions necessary to support store-&-forward communications services within very small budgets" (Ref. 3), offered to integrate a "digital communications experiment" (DCE) into their UoSat-2 spacecraft if it could be readied in less than six months! VITA hired a consultant to coordinate the technical activities of AMSAT and VITA volunteers on three continents, and in April 1984 UoSat-2 was successfully launched into space (Ref. 4).

Prototype messaging software on the DCE was largely developed by VITA consultants and volunteers and tested successfully at the Pacific Telecommunications Conference in Honolulu in January 1985, the trip funded by the IDRC. With financial assistance from VITA, full implementation of DCE messaging software occurred in

December 1985, and VITA's DCE groundstation was established in May 1986. Funds for the purchase of hardware for this station as well as a PACSAT design review held at VITA headquarters in March 1985 were provided by the Margaret W. and Herbert Hoover, Jr. Foundation (Pasadena, California).

Since 1985, hundreds of messages have been passed on the DCE among stations located in Europe (Surrey), the United States, Asia, Australia and New Zealand, even the Antarctic! The Surrey station alone handled 3 megabytes of traffic during October 1987 alone (Ref. 5).

Present Status

VITA has sub-contracted with Surrey Satellite Technology Ltd. to provide PACSAT-A and PACSAT-B, two space-qualified store-and-forward payloads which will support humanitarian and scientific communications in the early 1990's. Prototyping for these payloads will be carried out on the UoSat-D satellite currently under construction at Surrey and scheduled to be launched on an Ariane vehicle in early 1989. (Originally, the PACSAT prototype was to have flown aboard UoSat-C, scheduled for launch on a NASA Delta in the same timeframe, but this launch has been postponed for approximately one year).

The primary payload on UoSat-D will be the PACSAT Communications Experiment (PCE). The PCE is an orbiting packet node with 4 megabytes of message storage space and advances the work accomplished on UoSat-2 with the DCE. While the PCE system is being developed under contract with VITA, the flight of the PCE on UoSat-D and its use by radio amateurs is funded by the University of Surrey and AMSAT-UK. VITA is seeking a special experimental authorization to use non-amateur frequencies to carry out limited demonstrations and tests on the PCE. Such activities will include field trials under real conditions as one might experience in a remote location as well as tests with highly-portable groundstations using simple non-steerable antennas in conjunction with more powerful transmitters on the satellite.

VITA's support for PCE development and PACSAT-A and PACSAT-B payloads is provided by the U.S. Department of Energy and the Margaret W. and Herbert Hoover, Jr. Foundation.

APPLICATIONS

The need for inexpensive yet reliable store and forward communications in relief and development is graphically portrayed in the following excerpt from the October 1986 issue of **Disasters** (Ref. 6):

> An answer to a technical problem that takes minutes to obtain in Europe can take months to obtain in Somalia or Sudan. To give just one example, a medical advisor in Mogadishu needed background information on excretion of antimalarials in breast milk to help him decide on the details of a prophylaxis programme for about half a million people. The agency funding him had no staff in Europe who were themselves qualified to make a thorough search for this information or who knew who to ask to do it for them. The telephone calls necessary to set up and pay for a search through a Western information centre would have taken weeks, given the communications problems at that time. The solution was to get a friend who was passing through via Nairobi to pay himself for a search in Europe, personally photocopy the papers concerned, and then to mail the printout and copies of papers to Mogadishu. The total time needed to get the information on this routine enquiry was about four weeks. The programme was already underway when the material arrived. Hundreds of highly technical decisions affecting huge numbers of people are made every month in relief programmes with a bare minimum of scientific background data.

This is another way of saying that the accuracy of information is an important but insufficient condition for its use in developing countries. In order for most technical and logistical information to be employed in the execution of a project (or in this case, a relief operation) it must be timely as well as accurate in content. Scientists, engineers and physicians--frequently the source of crucial knowledge--are usually aware of the time dimension of technical information requirements in their professional activities; however, they may not always appreciate that good timing is also highly operative in relief and development projects.

This is not to say that every project always needs information within a few hours or even a few days. Indeed, many do not, but such projects also tend to be well-funded and staffed with reliable contacts within host government agencies which in turn have easy or priority access to international communication media. A refugee camp, an agricultural project in an isolated region, a scientist monitoring the spread of AIDS or the movement of locusts through remote sections of Africa all require the ability to transmit and receive technical data and information reliably when the situation demands. **These applications require that the communication link be reliably available on short notice without it having to be re-established each time "from scratch."** It is in these and similar situations where the existing international telecommunications infrastructure-- built on wide-band, highly sophisticated satellites and ground stations-antennas and the geosynchronous environment generally--leaves unfilled niches which low-cost LEO satellites, like PACSAT, can fill.

Information which is critical to project execution is time-dependent. This means that the same information, if delivered after a certain time, has lost much--if not all--of its value. This is frequently due to the intrinsic value of the information itself. Even more important is the potential loss of human and material resources that be may siphoned off into other activities or wasted altogether if not used when critically needed.

From the standpoint of planners, international development projects are sometimes viewed as objectives compartmentalized into specific activities, all having discrete beginning and ending points. From the perspective of field staff, however, it is often more realistic to consider accomplished objectives as having successfully recognized and exploited "windows of opportunity." When the "window" is "open," it is critical to have the right information at that time. When the window is "closed," (e.g., field staff have promised skeptical village leaders information on a new treatment for cholera but have not delivered same) it may be twice as difficult if not impossible to reactivate interest.

Most technical information which is actually used is the result of multiple pairs of query-response; each response provides more feedback for an ever-refined query. This makes the reduction of turnaround time important and suggests that communication modes that specifically address reliability and speed, particularly from isolated areas, have become enormously significant for a variety of rural projects and activities.

VITA envisions the PACSAT system in four main application areas:

1. Technical information transfer
2. Project administration
3. Data exchange for humanitarian ends
4. Disaster communications and response

Applications involving these four applications areas fall into two major categories:

1. VITA International Information Exchange System (VIIES)

2. Other non-VITA humanitarian and scientific networks authorized to use the PACSAT system

VITA envisions that approximately 60 stations will be found in

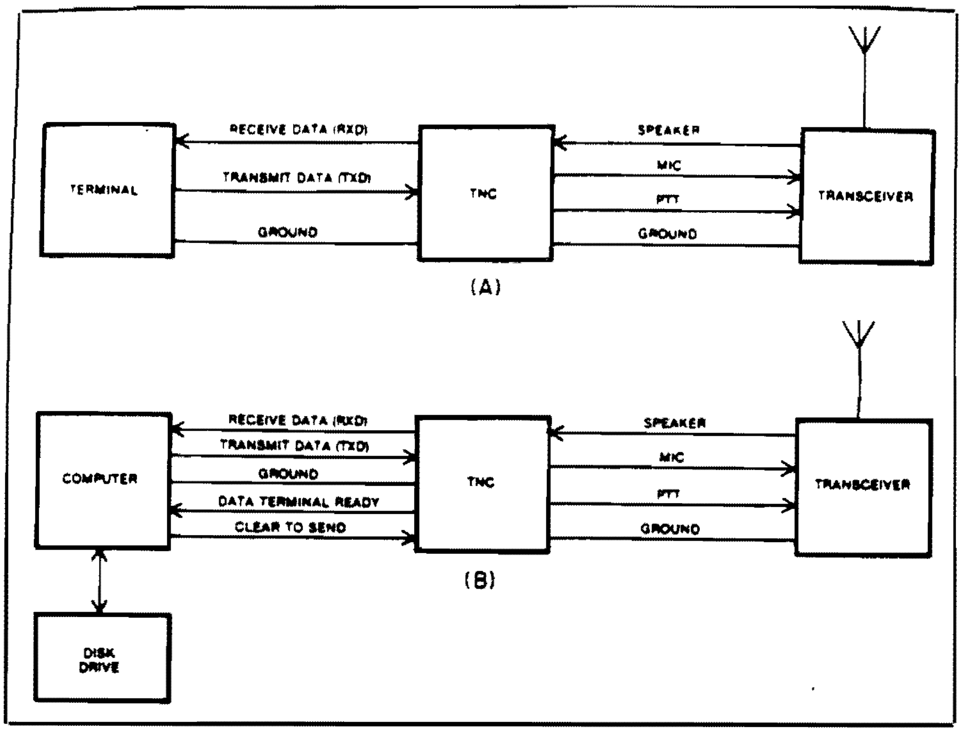

Fig. 2 - A shows the simplest TNC, radio and terminal connections. In B, the additional hardware flow control lines between the computer and the TNC make it possible to transmit large data or message files.

Source: QST, August 1985, p. 20

the VIIES category consisting of VITA's own field projects and technical documentation centers established with VITA assistance worldwide, with the majority in Africa. Each payload/satellite (PACSAT-A and PACSAT-B) will have the capability of supporting up to 500 ground stations within the following classifications (Ref. 7):

Man-portable

The man-portable terminal will be in essence a "small suitcase" containing a lap-top computer, a terminal node controller (TNC), VHF/UHF radio transmitter/receiver, batteries (with a solar panel charging option), and small vertical antenna. Fig 2 is a block diagram describing component relationships of a packet radio system. Such a station is designed to be highly mobile and can be set up and used immediately as a VIIES terminal. Within VIIES, there are 25 man-portables planned, with an estimated daily upload and download of 2 pages of text each (4 pages total per station).

Small-Fixed Stations

Small-fixed stations support ongoing communications with VITA field projects and are not expected to be "broken down" and re-established at another site. The small-fixed station, unlike the man-portable, will have a semi-permanent antenna installation and perhaps a standard-sized desktop computer with printer. Most installations will employ non-steerable antennas, although automatic antenna tracking could be provided optionally. Besides providing communications for ongoing VITA projects or stand-alone technical documentation centers, this size station may also serve as "gateway" for several small projects via terrestrial packet radio. Estimated VIIES stations total 25, with a daily uplink of 5 pages and a daily downlink of 5 pages per station.

Base Stations

Base stations are permanently installed in locations where there is mains power available and a facility for mounting steerable, non-tracking antennas. Base stations will be used where there is need for high-volume information flow. These include situations where the location of the station is in a regional capital city or near the national capital. The base station becomes a natural gateway for messages and files sent by terrestrial packet radio and/or telephone modems. As such, through-put both in terms of data as well as text will be appreciable. A base station will use desktop computer with suitable mass-storage devices and printing facilities. Estimated VIIES stations in this class total 15 and will be capable of a daily uplink of 25 pages and a daily downlink of 25 pages per station.

VITA Command Station

The station at VITA headquarters will be the PACSAT Command Station. In addition to acting as the primary (possibly only) U.S. gateway for VIIES, the Command Station maintains and manages the PACSAT messaging system. The Command Station is a fixed station, with automatic tracking antennas and amplifier (so that signals are not attenuated due to physical surroundings, thereby making useable the greatest portion of any given pass. A large fixed disk mass storage system as well as non-volatile archiving will be utilized. The VITA Command Station will be the source and destination of many messages on the PACSAT system. Processing inquiries into useful responses is the major function of the VIIES which will use VITA's existing resources, such as the expert Volunteer Database, Documentation Center and Inquiry Service, to provide responses with fast turnaround, thereby avoiding bottlenecks. A daily uplink of up to 350 pages and daily downlink of 350 pages is anticipated.

Non-VIIES stations will have some means for cost-reimbursement to VITA for use of the PACSAT system. Even before an operational PACSAT has been implemented, literally dozens of international development and relief organizations from around the world have expressed interest in providing communications services to their constituent groups via the system. Since each PACSAT can support up to 500 users, it is assumed that an initial implementation will include about 200 small fixed stations and 300 man-portables. The number of non-VIIES stations will be varied to fill the "excess" capacity available from the PACSAT.

Precise distribution of the VIIES and non-VIIES stations is not determined at this writing. We expect that VIIES stations will be located throughout Latin America, Africa and Asia (including Oceania). One half of the total (approximately 30) will be established in Africa (particularly concentrated in the Sahelian areas). The remainder (approximately 30) will be divided more or less equally in Latin America and Asia. Current high interest in PACSAT and packet radio technology generally in the Philippines might cause a disproportionate share to be established in that country.

SOME SOCIOLOGICAL CONSIDERATIONS

The role of technology in development is constantly debated. There are no simple answers or models that can be easily agreed upon. As a result, models of "technology transfer" processes are not easily implemented or replicated. In one instance, it may take a complex and time-consuming re-orientation of the educational process with parallel changes in social-political-religious values for a technology transfer process to take place (as illustrated by the adoption of family planning technology and methods). In another situation the adoption may be more or less spontaneous (an example is the rapid exploitation of cocoa cultivation technology by the Ashanti people of southern Ghana which took place without intervention of agricultural extension agents or foreign consultants).

Self-knowledge of the cultural "scripts" carried within "change agents" and especially international development organizations is a place to begin the analysis of whether a given technology has a chance of making either positive or negative changes and to what degree. A fundamental value that Western civilization has adopted for itself and which is inextricably bound up in the socio-economic-political milieu in which we find ourselves is that technical innovation is highly desirable and that without constant innovation our civilization is in danger of collapse. It is well-known that Americans have an obsession with gadgetry and technical innovation in general:

> Nouveaumania developed from the belief that novelty was a panacea. Faced with the need to innovate or adopt new ideas to survive, the American settler made the search for new ways of doing things a part of the American tradition. In recent years we have seen the results of the distortion of this tradition

> in the adulation of new technology, a disinterest in the past, and a pervasive sense of impermanence...
>
> In industrial America, old traditions are junked like worn-out cars and appliances. The rate of change has accelerated to the point where today people feel that nothing seems to work as well as it should, that they have somehow lost control over their lives. What is missing is the sense that the present grew logically from the past and that tomorrow will be continued from today. (Ref. 8)

In development, this obsession can frequently translate into a search for the "Holy Grail," the ultimate technological fix for problems which may have only partial technological solutions. In fact, the complicated and seemingly intractable problems in development do not have their roots only in the choice of technology, but rather in the unequal distribution of such resources as income, information, land, skills, etc. which perpetuates inequality in the distribution of socio-economic benefits of development to the population. The concern with equality as a primary dimension of development calls for a re-examination of the role of communication, and especially communication technology, in development. The basis for the re-examination of communication technology and its role in technology transfer processes is the criticism that such processes, when imposed from the outside, are imperfect equalizers of development benefits due to the unequal distribution of resources. In other words, individuals who already have greater resources usually benefit more from the innovations introduced by development agencies than those individuals who have fewer resources, thus widening the socio-economic benefits gap (Ref. 9).

As a highly innovative communications technology concept, the PACSAT project must be examined in this light. VITA expects that PACSAT technology, which is both sophisticated and de-centralized, has the potential for empowering projects and thereby local communities with that kind of time-dependent critical information that can result in making better choices and, in the aggregate, improving the standard of living. As an "appropriate" technology that has enormous potential for adding value to time-dependent information, the only way to know for sure what effect the PACSAT system has had is to carefully design an evaluation scheme as the system is implemented. Questions to be asked in such an evaluation design may include the following:

1. How accessible are present communication media? How and who controls this access?

2. How is the rural social and economic structure organized and what control does it exert over individual or project decisions?

3. Who decides whether the PACSAT system can be made available and to whom? Ar local people and/or project personnel consulted?

4. Will the PACSAT system have any measurable impact on individual or family welfare? On regional and national development in the short, medium and long range? Will it tend to increase employment or unemployment, fixation of the rural population or migration to the cities, enrichment of the already rich or better income distribution?

5. Does the adoption of the system have any implications for modification of local work habits, practices or even cultural norms?

6. How technically sound is the PACSAT system? What level of maintenance and problem-solving in the event of difficulties can be handled by users themselves and what needs to be supplied from the outside? What kind and levels of training must exist?

7. Are there any limits to time, duration, and destination of the communications? Is automatic logging at the ground-station sufficient for telecommunications authorities? How frequently is a groundstation checked or monitored? Is there any attempt at blockage or censorship of communication?

8. Do users of the PACSAT system have an effective means to communicate their needs and suggestions for improvement back to VITA? Does VITA have a systematic way of dealing with these concerns?

9. How important are the local personal or peer networks both in formulating the questions or topics requiring information as well as disseminating the results?

10. Does the PACSAT system help identify local resources that users might not have known about previously? Can identification and use of these local resources eventually replace PACSAT as an international communication media for far-away resources or is PACSAT-type communication required "in perpetuity"?

AN OVERVIEW OF REGULATORY ISSUES AFFECTING PACSAT

As mentioned earlier, the level of response and interest from the international community for use of PACSAT in relief and development (as well as scientific communication supporting humanitarian ends, such as AIDS monitoring) has been enormous. At this time it is perceived that once the system is fully functional in both space and ground segments that there will be no dearth of non-VITA users. Indeed, a major task for VITA may well be to screen those potential users who are merely fascinated by the technology from those who truly have time-dependent information needs. Even with this level of interest, which already includes some well-placed government and international officials (in United Nations agencies, for example), it is not at all clear what regulatory and/or political pitfalls may await actual implementation of the PACSAT system.

It is expected that the choice of frequencies will be an issue of major concern. The basic problem is that the provision for LEO store-and-forward digital communications is not specifically recognized in the ITU Table of Frequency Allocations. Therefore, there are no easily identifiable frequency sub-bands currently in the radio spectrum within which authorization for this service can be given. VHF/UHF frequencies are preferred because of the relative simplicity of equipment (and especially antennas), but these frequencies are also crowded with existing government, military and commercial assignments.

Given this situation, there appears to be two general approaches to solution of the problem: 1) prepare a full-scale political/technical package to be presented at the next World Administrative Radio Conference (WARC) that will deal with proposed PACSAT frequency allocations, or 2) attempt to "umbrella" the system under existing definitions of the radio spectrum used for communications from space (for example, "space research" or "space operations") and hope that governments, seeing the humanitarian and strictly non-commercial nature of the communications, will not oppose such broad interpretations. VITA, at this writing, has not yet decided which alternative to select. The former requires a great deal of time and energy (and money) but an attractive case could be formally developed, while the latter is perhaps less costly but is certainly riskier.

In either case, governments will have to be convinced that the PACSAT system, while it bypasses ground-based communications systems, does not imply unnecessary security risks. Developing countries in particular are quite sensitive to the by-pass issue. We have suggested that tamper-proof groundstation-based logging could solve this problem, but whether this will be widely acceptable is not yet known.

International regulations generally forbid the use of amateur radio frequencies for cross-border communications of a humanitarian nature, except in the event of "emergencies" or where bilateral agreements allow "third parties" (non-amateurs) to send and receive non-commercial, non-routine messages. Even the interpretation of what constitutes an "emergency" or "non-routine" message varies widely. In the United States there is a long tradition of using amateur radio in the public service, while this is not generally true in Europe. Since many African and Asian countries derive their administrative apparatus and attitudes from the period of European colonialism, it is not surprising that these same restrictions may apply to amateur radio operators from those countries.

Taken as a group, radio amateurs are extremely sensitive to any proposed operations in their bands which might tend to obfuscate use of their allotted spectrum for fear that such spectrum could be eventually lost. For example, **The 1988 ARRL Handbook for the Radio Amateur**, while mentioning that "a critical design review for the PACSAT project was held...in Arlington, Virginia" did not identify VITA as the venue for the meeting, presumably because it did not want to elicit criticism or scrutiny of the experimental links between PACSAT system development for humanitarian ends and amateur radio (Ref. 10). While there has been some speculation of the desirability of modifying the amateur regulations outright so that future non-emergency humanitarian uses of the amateur spectrum could legitimately be included, VITA has taken the position that the orchestration of such proposed changes is so delicate and intrinsically difficult that the better approach is to look for operational frequencies outside the amateur bands entirely.

For operation of the PACSAT Communications Experiment (UoSat-D) on VITA-sponsored field demonstrations and experiments, VITA hopes to acquire authorization to use non-amateur frequencies on an experimental basis for a finite period of time. Even if these frequencies are approved, there is not necessarily any correlation between those experimental frequency allocations, and frequencies finally selected for future operational PACSATs.

CONCLUSION

While it is still too early to say that LEO store-and-forward packet radio satellites are "here to stay" for relief and development applications, the possibilities are immense and have fired the imaginations of many individuals in the international development community who see PACSAT as a possible solution to the age-old problem of communicating from isolated regions.

As with all technologies, a fundamental concern for the successful application of packet radio satellites (as well as the link to terrestrial packet systems) is relevant integration into well-designed projects or plans of action as appropriate, high-technology tools of the twentieth century, and not a mere "solution looking for a problem to solve." Problems of international frequency allocation and authorization are difficult and solutions, while not clearly identifiable at the present time, are associated with larger issues of who ultimately controls the technology and its use.

Undeniably, however, the "missing link" of providing inexpensive yet reliable communications from remote locations and integrated into the existing international communications infrastructure provides fascinating possibilities for the application of science and technology to the problems of development.

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